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SEAM-WELDED AIR HARDENABLE STEEL TUBING**5 INVENTORS:** Edward J. McCrink and Davor Jack Raos**Related Applications**

Filed concurrently herewith is an application entitled SKINNED AIR HARDENABLE STAINLESS STEEL STRUCTURES AND METHODS OF
10 MANUFACTURE THEREOF (Ref. No. 4800-0005).

Field of the Invention

The field of the present invention is seam-welded, air hardenable steel tubing and pipe, structures created therefrom and methods for manufacturing seam-welded, air hardenable steel tubing.

15 Background of the Invention

A seam-welded, air hardenable steel tube substantially free of cracks in the weld zone has not been proposed in the prior art. "Air hardenable steel" is herein defined as steel that reaches a level of hardness sufficient to cause cracking when processed in a prior art roller-forming tube mill. Other steels which are sometimes called "air hardenable" do not reach a comparable level of hardness and therefore do not crack when processed in a prior art roller-forming tube mill; these steels are categorized herein as "partially or non-air hardenable" steels.

An example of a non-air hardenable steel currently used to manufacture seam-welded tubing is 4130 steel (UNS G10220). This steel does not crack when formed in a prior art roller-forming tube mill; however, it must be liquid-quenched after heat-treating to attain a high strength and unfortunately this liquid quenching tends to induce high levels of distortion. As a result, liquid quenched materials like 4130 have limitations when used for applications requiring frame-type structures that must be straight and free from distortion. An example of such an application is a bicycle frame. Theoretically, the highest strength-to-weight ratio would be attained if the parts could be welded together and then heated and liquid quenched as a whole, resulting in a frame with uniformly high-strength throughout all areas. However, liquid quenching an entire frame at one time would distort it beyond acceptable limits. Instead, when made from this material, bicycle frames

must be constructed of individual tubes that are hardened prior to assembly and then welded or brazed together. Because welding or brazing causes localized weak areas, thicker tube walls must be used to compensate for the loss of strength and this ultimately reduces the strength-to-weight ratio of the frame. In some 5 applications such as high performance bicycle frames, the tube wall is thickened only in those areas that will be weakened by welding or brazing to minimize the reduction of strength-to-weight ratio. Although saving weight, such measures require expensive extra processing steps such as drawing the tube. In summary, although liquid quenched steels like 4130 fill the immediate need, a great 10 improvement in overall utility, usefulness and economy would be realized if a low-cost tubing capable of producing a structure of a higher strength-to-weight ratio were available.

One example of a partially air hardenable steel used for tube making is 410S (UNS S41008), made available by Allegheny Ludlum of Pittsburgh, 15 Pennsylvania. 410S is a low carbon modification of 410 (UNS S41000). The low carbon level (0.08 % maximum) of 410S prevents austenite formation upon heating, thereby preventing martensite formation upon cooling. This means that the metal doesn't crack in a prior art roller-forming tube mill, but also that it doesn't harden to a high strength condition. Tubing comprised of 410S lacks the 20 strength needed for high performance load bearing applications.

Another example of partially air hardenable steel tubing is True Temper OX Gold and Platinum series tubing, produced by True Temper Sports, Inc. This is a non-stainless tubing intended for use in expensive bicycle frames that is first roller-formed and seam-welded, and then drawn. Although this steel achieves a 25 high strength without cracking in a prior art roller-forming tube mill, it only does so due to the addition of expensive alloying components. As explained in the company's website at the address <http://www.henryjames.com/oxplat.html>, these alloy steels are specially formulated to mitigate the difficulties inherent in the welding of air hardenable steel. Modifying the material to prevent cracking results 30 in an expensive, specialty tubing with limited usefulness; for most structural applications, its cost cannot be justified. Rather than resort to the use of expensive alloys, it would be beneficial to create a process that could utilize common, inexpensive, air hardenable steel to produce tubing substantially free of cracks.

Such a process would be even more beneficial if the work material could have the corrosion resistant properties of stainless steel.

Through discussion with practitioners in the industry, it is apparent that experimentation with seam-welding tubing of air hardenable steel was abandoned 5 due to the heretofore-insurmountable problem of cracking. In standard tube production practice on a prior art roller-forming mill, the metal in the weld zone is heated and subsequently cools at a natural rate, which is sufficiently rapid to induce hardening of the material if the material is of the air hardenable or partially air hardenable type. The longitudinal stresses induced by weld zone shrinkage 10 together with the compressive stresses induced by the sizing and straightening rollers are therefore acting on material that is in a hard and somewhat brittle state. If the material being formed becomes hard and brittle enough, the weld zone will crack and a sound tube cannot be produced. The prior art provides no indication that efforts in solving this problem were fruitful, if, in fact, any such efforts were 15 made. Perhaps because the applicability of such tubing to a vast range of structural purposes was not envisioned, efforts to solve the problem were either never undertaken or were abandoned, and it became an accepted fact in the industry that only non- or partially air hardenable steels can be successfully roller-formed and seam-welded.

Historically, air hardenable steel has been mainly used in applications that do not require welding. Air hardening steels, such as martensitic stainless, were first commercially developed for use in cutlery. Common uses of air hardenable stainless steel include knife blades, surgical instruments, shafts, spindles and pins. Air hardenable stainless steels include a relatively high carbon content compared 25 to other stainless steels (0.15% maximum in 410 to 0.75% maximum carbon in 440), and between 12 and 18% chromium. This composition results in steel with good corrosion resistance and the ability to harden via heat treatment to a high strength condition, but one that presents difficulties related to welding. Non-stainless air hardenable steels, which are much more expensive than stainless 30 types, also present difficulties related to welding, and have been primarily used for cutting tools.

In a minority of applications for air hardenable steel, welding is used to join separate pieces of the material. For these applications, textbooks related to the field teach a "preheating" method to control cracking. Using the preheating

method, each entire workpiece is heated prior to welding. The latent heat in the workpieces reduces the cooling rate of the welded seam, and cracking is thus inhibited. However, there is no indication in the prior art that the preheating method was successfully applied to seam-welding roller-formed air hardenable steel into a tube—as can be seen by the fact that such a tube is not available. This may indicate limitations inherent in the method of preheating—for example, the method may only be reliable for relatively short welds joining relatively small workpieces, where accumulated stresses due to weld shrinkage are relatively low and significant cooling of the workpieces does not occur before the weld bead is run from one end to the other. Or, it may indicate that others in the industry did not envision applying the method to the production of seam-welded air hardenable steel tubes, perhaps because they did not envision the tremendous utility of this type of tubing.

The use of air hardenable steels for structural applications was introduced in U.S. Patent No. 5,485,948 and further described in U.S. Patent No. 5, 871,140. These patents provide brazed structures that take advantage of the fact that air hardenable stainless steel can be simultaneously brazed and hardened in one furnace pass, including structures containing drawn tubing. Use of a lock seam tubing brazed and hardened in this manner was seen as having advantages in producing load bearing structures at low cost. It was a good idea to propose air hardening materials in tube form as a general-purpose structural medium because of the tube's superior effectiveness (compared to other shapes such as solid bar or I-beam) when loaded in compression and torque, and also in bending when multiple tubes are assembled into a truss. However, the proposed lock seam increases the weight of the tubing, creates a stress riser and an uneven exterior and/or interior surface, and causes the tube to bow or distort when it is heat-treated.

Drawn air hardenable stainless steel tubing is found in the prior art and is available for purchase; however, it is prohibitively expensive for most structural applications.

Due to the performance liabilities of lock seam air hardenable stainless steel tubing and the expense of drawn air hardenable stainless steel tubing, we determined that seam-welded air hardenable stainless steel tubing would give the highest overall performance for most structural applications. But, we discovered

that seam-welded air hardenable steel tubing, of either the preferred stainless type or of the non-stainless type, was not available. No one had solved the technical challenge of producing seam-welded tubing from air hardenable steel strip such that the tubing's heat affected zone is substantially free of cracks. Accordingly,

5 the prior art did not provide a seam-welded, air hardenable steel tube.

Other than U.S. Patent Nos. 5,485,948 and 5,871,140 and related international filings, the prior art did not describe the use of air hardenable stainless steel for structural purposes, although this is not surprising due to the difficulties involved in welding this material as described herein above. The most

10 common structural materials in use today include reinforced concrete, mild steel, high strength steels, aluminum alloys, woods, and exotic materials such as carbon composites and titanium. Specific application requirements govern the selection of a structural material and the engineer chooses on the basis of factors such as cost, durability, corrosion-resistance, strength-to-weight ratio and stiffness-to-weight

15 ratio. Unfortunately, the choice often requires the engineer and ultimately the users of the structure to sacrifice one or more desirable features, such as low cost, safety, lightness, or durability.

Structural materials are currently available in a broad range of strength-to-weight ratios, but the costs of these materials generally increase disproportionately

20 to their strength-to-weight ratios. Carbon composites and titanium, for example, while being perhaps ten times stronger than mild steel for a given weight, are typically more than fifty times more expensive when used to bear a given load. Consequently, such high performance materials are typically used only in small items, such as bicycles and tennis racquets, or in applications where the high cost

25 is justified, such as in aircraft.

In cost-sensitive applications such as cars, conventional structural materials force a trade-off between cost and fuel efficiency, safety, and performance. Consequently, the typical car tends to have a frame that is both too heavy and too weak. A heavy frame requires a more powerful propulsion system,

30 which leads to higher fuel consumption, higher emissions, and higher maintenance costs. The more powerful propulsion system is itself more expensive to build, uses more material, requires more energy to produce and leads to more emissions related to its manufacture. A weak frame compromises the durability of the vehicle and the safety of its occupants.

Lack of a strong and lightweight yet low cost structural material is the number one hindrance to the development of economically viable low emissions vehicles—vehicles that can compare in performance, safety, comfort, and price to those powered by the typical internal combustion power system. Without a 5 light, economically competitive structural material to enable alternative power systems for moving vehicles, drastic emissions reduction will be extremely difficult to realize. Current lightweight alternatives to common steel for vehicle bodies are aluminum, plastics, high-strength steels, and exotic materials like magnesium and titanium. None of these materials can offer the required set of 10 performance parameters for the frame elements of a vehicle, at a sufficiently low price. Some of these materials are superior to mild steel in one respect or another, but their cost offsets the advantage. In other respects, their performance is worse than mild steel.

With no lightweight structural material offering a quantum overall 15 advancement in performance and price over mild steel, design of a lighter vehicle is an exercise in balancing trade-offs, offsetting disadvantages as well as possible. For example, vehicle lightness and safety are traditionally inversely related. In a 1997 article¹ that surveys the currently available lightweight alternatives for 20 vehicle bodies, two MIT professors wrote, “a lightweight car cannot rely on its structural components to protect passengers in the event of a crash and so will need to employ additional systems, like airbags, which add some weight.” With the current choice of structural materials, it is likely that lightweight vehicle body research and development will be a lengthy and expensive process, with no certainty of reaching the performance and cost targets.

25 Compromises between objectives, brought about by structural material limitations, can be seen in many other areas and are being found increasingly unacceptable. For example, reinforced concrete bridges are weak and heavy, subject to failure in earthquakes and susceptible to aging. They also must be built on-site and take too long to build, which means new bridge construction 30 undertaken to alleviate traffic congestion aggravates the problem during the lengthy construction period. Alternative bridge-building materials such as carbon composites are much stronger than reinforced concrete, and bridges of these

¹ “A Practical Road to Lightweight Cars,” by Frank R. Field III and Joel P. Clark, January 1997.

materials can be erected faster than their concrete counterparts, but these materials are prohibitively expensive.

Solving traffic congestion problems is also dependent upon the development of a structural material that will deliver the required performance
5 characteristics at a supportable cost. In many urban areas, the cost of expanding highways and freeways is prohibitive. Expanding vertically—building elevated inter-city high-speed trains and elevated “double-decker” freeways—is often proposed, but subsequent calculations of construction costs for the elevated railway or roadbed prohibit widespread adoption of these space-efficient
10 solutions.

In building construction, the advantages offered by steel framing, of the type described in the prior art, are offset by its increased cost over traditional structural materials such as wood and masonry. A conventional steel-framed building is safer, more durable, and more energy-efficient than a comparably sized
15 wood-framed building—but also more expensive.

Compromises between cost and performance can be seen in many other structural applications, such as aircraft, ships, bicycles, fluid and gas transfer piping, and heat exchangers. We recognized that if seam-welded air hardenable steel tubing could be created, and specifically if it could be created through an
20 inexpensive process using stainless steel, it could provide structural characteristics similar or superior to much more expensive materials. Such tubing would represent a revolution in the world of structural materials, on which we all so heavily rely.

Summary of the Invention

The present invention provides a steel tube comprising air hardenable steel and a longitudinal welded seam, the tube characterized by a heat-affected zone substantially stable and free from cracks. As defined herein, an air hardenable steel is one that when welded and processed in a prior art tube mill will tend to crack. Air hardenable steels do not include steels specifically modified to partially inhibit hardening and thereby circumvent such cracking tendency. Therefore, as defined herein, OX Platinum is an example of steel excluded from the air hardenable steel category.

The preferred embodiment of the present invention is a seam-welded tube of air hardenable stainless steel. This embodiment provides revolutionary steel tubing that will enable new technologies and find widespread use in many diverse applications including moving vehicles, aircraft, bridges, buildings, fluid and gas transfer piping, elevated railways and roadbeds, heat exchangers, and ships. The principal advantages of this new tubing lie in its high strength-to-weight and stiffness-to-weight ratio, lightness, low cost of production, resistance to corrosion, and modular construction and pre-fabrication possibilities. A structural material with these advantages can solve many critical problems currently facing industry, government, and society at large, including pollution, traffic congestion, moving vehicle safety, aging transportation infrastructures, and structural damage, loss of human life and economic waste from seismic and weather related catastrophes.

For many applications, seam-welded air hardenable stainless steel tubing provides better performance for its cost than any other structural material available today. For structural applications, a critical consideration is the strength-to-weight ratio of a given material versus its cost per unit strength. Figure 1 provides a comparison of the present invention (represented by the diamond) to the prior art in this regard. The chart shows the inverse relationship between cost and strength-to-weight ratio for traditional structural materials: the better the strength-to-weight ratio, the higher the cost. When plotted on the same chart, the present invention is distinctly off of the linear progression defined by the traditional materials. This graphically demonstrates the tremendous advancement in performance per unit cost afforded by the present invention.

The tubing of the present invention also provides higher stiffness for a given weight and cost than currently available structural materials. This factor will

allow the safety and performance of many structures, both moving and stationary, to be improved.

The seam-welded air hardenable stainless steel tubing of the present invention is so cost-competitive because the alloying constituents (iron, carbon, and chromium) are inexpensive and plentiful and because the methods of production of the present invention are suitable to automation, enabling a high quality product to be produced without the use of high-cost labor. This contrasts with the high labor costs incurred in the production of drawn air hardenable stainless steel tubing.

The present invention's inherent corrosion-resistant properties often allows an additional weight savings because painting, zinc coating, or engineering thicker walls in anticipation of corrosion is unnecessary. Unsightly galvanized finishes, which are damaging to the environment when they are applied, can be eliminated. The tubing of the present invention can be made in a wide range of colors with no additional processing—including silver, black, and subdued hues of red, blue, green, and gold—simply by varying the temperature point in the heat treating process at which the material is transitioned from a controlled atmosphere to air. This finish can enhance the appearance of many articles.

The appearance of many articles can be further improved due to the high strength-to-weight and stiffness-to-weight ratios of the tubing, which allows structures to be designed with more slender, less imposing profiles. For example, overhanging freeway sign structures, which are typically blocky, galvanized, and unsightly, can be made much more aesthetically pleasing.

The present invention provides methods of manufacturing seam-welded air hardenable steel tubing that include controlling the cooling rate of the heat-affected-zone. The cooling rate is reduced to the point necessary to substantially reduce hardening of the heat affected-zone following seam welding. Embrittlement, and thus cracking, is effectively eliminated by the present invention.

Although the tube-making methods disclosed herein could also be used to create sound tubes of non-stainless air hardenable steels, at the present time there is no non-stainless air hardenable material that can compete in cost or performance with air hardenable stainless steel, and therefore such tubes would not be desirable for use in structural applications. However, it is anticipated that

various new formulations of air hardenable steel, including both new non-stainless and new stainless types, may be developed in response to the availability of the new methods of tube making disclosed herein. Since these new formulations may indeed be competitive with, or even superior to, currently available air hardenable
5 stainless steel for some structural applications, it is an object of the present invention to use the methods herein described to seam-weld both stainless and non-stainless steels that are air hardenable.

It is likely, for example, that the carbon content of 400-series type stainless steel will be specified at percentages between the present 400 series intervals, and
10 held to tighter tolerances. For example, 410 contains .12% carbon with approximately $\pm .02$ percent tolerance and 420 contains .25% carbon with approximately $\pm .04$ percent tolerance. A new specification, labeled 415P perhaps, with a carbon content of .19% and a tolerance of $\pm .01$ percent may be created.

Also, it is anticipated that new air hardenable steels containing constituents
15 other than carbon, chrome and iron may be developed in order to improve various characteristics of the steels for various specific applications. Insofar as these new steels could not be seam-welded into a tube without the methods of production taught herein, seam-welded tubing of these steels would be considered to fall within the scope of this patent.

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Brief Description of the Figures

Figure 1 provides a relative strength/weight/cost chart.

Figure 2 provides a side view of a tube mill of the present invention.

Figure 3 provides a top view of a tube mill of the present invention.

Figure 4 provides a cooling profile chart.

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Figure 5 provides a side view of a static structure of the present invention.

Figure 6 provides a side view of a mobile structure of the present invention.

Detailed Description of the Invention

The present invention includes methods of creating tubes and tube-based structures from air hardenable steels, including stainless steels. The specific
30 combination of steps and materials set forth herein have never before been identified as together leading to a quantum improvement in the strength/weight/cost ratio of tubes and tube-based structures.

The absence of seam-welded air hardenable steel tubing on the market, together with the realization that such tubing would fill a large void in the world of structural materials, led to the invention of the methods of tubing production disclosed herein. After surveying the failed efforts of others in the industry to 5 seam-weld air hardenable steel, we realized that the capacity to air harden is both the most necessary characteristic to create steel tubing of the desired overall performance and the biggest stumbling block to its creation.

The air-hardening characteristic specifically allows a tube-based frame or other structure to be hardened to a high strength condition without concomitantly 10 introducing an unacceptable amount of distortion, such as is the case with liquid quenching. However, the air hardening characteristic of the steel also leads to cracking after welding in a prior art roller-forming mill, which led others in the industry to conclude that such material could not be seam-welded into a tube.

15 The present invention includes methods that make the production of seam-welded tubing from air hardenable steel possible for the first time. The preferred method of the present invention includes positively controlling the cooling rate of the weld zone immediately following welding on the mill, such that the weld zone never becomes fully hardened. This cooling rate control consists of applying heat 20 to the seam downstream of the weld box to prevent rapid heat loss.

The preferred method of the present invention consists of the following steps:

Air hardening steel strip is roller-formed into a tube (step 1) and seam-welded in a 25 continuous process (step 2). Immediately following welding, and prior to sizing, the weld zone-cooling rate is positively controlled (step 3). The cooling rate is held to a profile that prevents the weld zone from fully hardening and becoming brittle, so that welding-induced stresses and sizing and straightening pass pressures do not crack the weld region.

30 Preferably the welding process is a gas tungsten arc welding process, formerly known as the tungsten inert gas process (TIG).

Preferably, the weld zone cooling rate is positively controlled through the use of a torch assembly or induction coil applied to the tubing downstream of the weld box.

Under certain circumstances, cooling rate control and thus crack prevention may be effected in the tube-making process by preheating the steel strip prior to welding. Although references to preheating as a method of controlling cracking when welding air hardenable steel exist in the prior art, they focus solely on joining separate pieces of the material as opposed to producing tubes. The preheating method is a relatively imprecise and unreliable method of cooling rate control, and its prevalence in manuals teaching the art may have hindered the development of other, more positive methods of cooling rate control, such as the preferred method disclosed herein. In addition to being less precise and reliable, the preheating method is also less energy efficient than the positive cooling rate control method taught herein. Nevertheless, under certain conditions such as when warm ambient temperatures exist or when the strip being rolled is of a sufficient thickness, preheating the strip may be sufficient to produce a seam-welded air hardenable steel tube substantially free of cracks. Insofar as this method has not been proposed in the prior art as a method of producing seam-welded air hardenable steel tubing, and it was not envisioned that this specific application of this method could produce a novel structural material with great utility, it is an object of the present invention to create seam-welded air hardenable steel tubing using the preheating method as the only source of cooling rate control.

Insulation of the tube downstream of the weld box to minimize heat loss to the surrounding air would maximize the chances of success in using the pre-heat system as the sole means of cooling rate control. It is also conceivable that under certain circumstances, best results would be achievable through the application of both preheating and post-heating methods of cooling rate control, in the same process.

It will be noted that in the present invention the tube mill was modified to suit the best material rather than, as in the prior art, modifying the material to suit prior art tube mills, to the detriment of tube performance. Accordingly, the present invention includes a new type of tube mill for the creation of seam-welded air hardenable steel tubing.

To create a very light and strong frame structure, individual tube sections produced by one of the above methods are welded to form a frame of the desired configuration (step 4), and then the entire frame structure is heat-treated (step 5) to bring it to a uniformly hardened, high-strength condition. The frame weldment

can include other components such as plates and flanges when required, which may or may not be made of air hardenable steel. After heat-treating, all air hardenable parts of the resulting structure are in the same high strength condition. Thus, the structure can be made free from weak spots, eliminating the need for 5 thickened (butted) tube walls at the ends of the tubes, such as those traditionally used in many bicycle frames.

For other applications, where the tube will not be subsequently welded into a frame structure, the tube can be heat-treated to a hardened, high strength condition as it exits the tube mill, in a continuous process. Alternately, such 10 individually-heat-treated tube sections may be assembled into a frame structure and then the entire structure can be heat-treated.

For applications where complex tube shapes are desired, the tube can be hydroformed, and subsequently heat-treated if desired.

15 **Facing layer**

The flat air hardenable steel strip from which the tube is made can be faced on one or both sides with a thin layer of a different type of metal, before it enters the roller-forming mill. Alternately, the facing layer(s) could be applied after the tube is formed. This technique can be employed, for example, to provide a higher 20 corrosion resistance than the base tube would provide alone. A typical facing material for use in highly corrosive environments can be 316 stainless steel. Other criterion may be used for the selection of facing materials as well, such as electrical conductivity, surface roughness, surface friction coefficient, color and appearance.

25 The facing layers can be applied to the strip stock or base tube by lamination, plasma spraying, or other commonly known methods. In the favored embodiment, the facing layers would be applied to the strip stock by pinch rolling, such that the facing is welded to the substrate strip as the facing and strip pass between two rollers.

30 The facing layer on one side can be composed of a different type or thickness of metal than the facing layer on the other side. Tailoring the facing layers individually would be appropriate, for example, in applications where the corrosive conditions found on the inside of the tube differ from those found on the outside, as is often the case in heat exchangers.

As explained in the following sections, seam-welded air hardenable stainless steel tubing is ideal for many applications and offers great potential to remove many of the compromises between performance, environmental safety, and personal safety on the one side, and cost on the other, that are necessarily tolerated today.

5 **Moving vehicles**

The present invention provides moving vehicle frames constructed of seam-welded air hardenable stainless steel tubes. Figure 6 provides a representation of a vehicle frame of the present invention. Vehicle frames of this 10 material would be substantially lighter than conventional vehicle frames, allowing smaller propulsion systems and thereby increasing fuel efficiency and reducing vehicle cost. Due to its high strength-to-weight ratio and stiffness-to-weight ratio, the present invention will enable alternative power motor vehicle technology, such as electric, hybrid-electric, or fuel cell powered vehicles. Vehicle frames can be 15 made lighter much less expensively than through the use of existing composite materials or common steel. The availability of lighter vehicle frames would mean alternative power sources currently being developed could finally economically compete with the internal combustion engine. Many societal benefits would accrue from the popularization of cleaner and potentially more efficiently powered 20 vehicles, including, most notably, emissions reduction. The tubing of the present invention could therefore contribute to the reduction of global warming, inasmuch as it is caused by vehicle emissions.

In addition to reducing vehicle weight, the present invention would also 25 vastly improve motor vehicle safety. Like high-performance racecars but without the attached price tag, vehicles sporting a frame of this high strength-to-weight and stiffness-to-weight tubing would protect occupants from injury and death much better than a comparably sized conventional vehicle. The crashworthiness of rail cars, a major concern to the U.S. Federal Railroad Administration and its counterparts in other countries, could also be significantly improved through the 30 use of this new structural material.

A breakthrough in vehicle durability can be realized through the use of seam-welded air hardenable stainless steel tubing as a structural medium. The material's inherent corrosion-resistant properties make painting, zinc coating, or engineering thicker walls in anticipation of corrosion unnecessary. Stainless steel

tubing can last virtually forever; when other vehicle components wear out and the vehicle is discarded, the tubing frame or components thereof can be re-used and recycled.

A structural frame of seam-welded air hardenable stainless steel tubing can
5 be fabricated largely by robot with a minimum use of hard tooling. The tooling for
a particular model of car, for example, would consist mainly of software
programs. This will allow for much quicker, easier, and less expensive production
setup for each new model, as well as allowing a given production line to quickly
switch between different models.

10 The present invention offers additional advantages for moving vehicles
used for commercial purposes, such as trucks with flatbed trailers. Without
compromising strength or durability, the present invention can substantially
reduce the weight of these vehicles, thereby enabling their operators to carry more
payload and increase profits. Furthermore, overall efficiency of cargo hauling is
15 increased with attendant reduction in environmental damage.

The present invention would enable high-performance golf carts that are
much lighter than comparably priced carts available on the market today. Vehicle
lightness is important in this application to minimize damage to the golf course.
Other types of utility vehicles, including Neighborhood Electric Vehicles, could
20 also be produced at a lower cost and with higher performance through the use of
seam-welded air hardenable stainless steel tubing.

Other moving vehicle applications that would benefit from seam-welded
air hardenable stainless steel tubing include utility and boat trailers, buses,
recreational vehicles such as snowmobiles and all terrain vehicles, and various
25 kinds of pushcarts, including wheelbarrows and service carts such as those used in
hotels and aircraft.

Bridges

Another excellent application for the tubing disclosed herein is bridges.
Many of the world's bridges need to be replaced due to age or because they
30 weren't built to support today's volume of traffic and have become "bottlenecks"
exacerbating traffic congestion. In the United States alone, 30.45% of the total
bridges, according to the National Bridge Research Organization, are targeted for
replacement. Two problems governmental organizations face in undertaking a

project of this magnitude are cost and traffic disruption; both of these problems are solved with the new structural material disclosed herein.

Using this tubing system, total costs for bridge construction can be a fraction of the costs incurred by using conventional structural materials, including 5 reinforced concrete, high strength steels, and composites. One source of this cost savings is that the material lends itself to the pre-fabrication of entire bridges or parts of bridges off-site, thereby minimizing traffic disruption and concomitant economic losses caused by lengthy on-site construction.

The ability to pre-fabricate a bridge off-site, made possible by the present 10 invention, enables the construction of cost-effective, modular, temporary bridges in addition to permanent structures. It is envisioned that governments and relief organizations could stock an inventory of such modular bridges for fast deployment to relieve human suffering and prevent economic losses when floods occur. The military also requires temporary bridges that are mobile/portable 15 (lightweight), can be produced at low cost, and are impact resistant. No structural material currently in existence can meet all of these requirements; the current solution being considered for military use is composite materials, which are lightweight but carry an extremely high price tag and could shatter from the shock of a nearby explosion. Also, composites have poor heat tolerance. By contrast, the 20 present invention enables low cost, lightweight bridges that can withstand shock and heat.

Seam-welded air hardenable stainless steel tubing is also a superior bridge-building material in terms of earthquake safety, a major concern in the industry.

Bridges of seam-welded air hardenable stainless steel tubing would perform vastly 25 better than reinforced concrete bridges or traditional steel bridges during seismic disturbances. Indeed, the vulnerability of concrete pillars can be seen in the efforts transportation departments are currently exerting to retrofit them with steel jackets. The support pillars of a seam-welded air hardenable steel tubing bridge would have a much lighter load to carry than its concrete counterpart.

30 Due to the corrosion-resistant properties of this new structural material, bridges of the future won't age. This is good news in the face of the vast amount of resources expended worldwide to maintain conventional bridges.

Finally, unlike conventional bridges, bridges of seam-welded air hardenable stainless steel tubing, even those not specifically designed as

temporary or mobile bridges, can be disassembled, moved, and quickly erected in a new location at a moderate cost.

Elevated railways and roadbeds

The present invention also lends itself to the construction of extremely 5 long "bridges"——i.e. elevated railways and roadbeds. Figure 5 provides a representation of the invention.

Population growth and ever-increasing traffic congestion has focused worldwide attention on the need for alternative transportation solutions such as inter-city high-speed trains, yet the costs of these proposals to date have been 10 prohibitive in many instances. To clear urban traffic and retain the high speed that would enable it to compete with airliners and automobiles, the entire railway or parts of it would need to be elevated. Currently available structural materials for such an elevated track are expensive and require support pillars at frequent intervals. The present invention would enable a much less expensive elevated 15 railway, with longer spans between support pillars. Indeed, it is envisioned that the reduction in cost for the elevated structure will offset the cost of magnetic levitation (Maglev) trains, which are generally agreed to be superior to conventional steel-wheel-on-steel-track trains due to their quiet operation, better acceleration, ability to climb steeper grades, and significantly reduced 20 maintenance requirements.

The present invention would also provide a cost-effective and high performance solution for elevated structures for other types of trains, including intra-city or airport monorails, light rail systems, and People Mover systems.

Cost and other factors related to purchasing a right-of-way corridor are 25 prohibitive to the expansion of highways and freeways. Constructing a "double-deck", or viaduct, above an existing highway via conventional means is also prohibitively costly. Unable to expand highways and freeways horizontally or vertically, transportation departments are left in a quandary as to how to solve traffic congestion. The present invention would make elevated roadbeds a viable 30 solution. Using seam-welded air hardenable stainless steel tubing in place of traditional structural materials, construction of an elevated roadbed would be considerably less expensive—due to both lower material costs and the ability to pre-fabricate the structure off-site, thereby minimizing traffic disruption. Using air

rights above existing freeways and highways, transportation departments can increase road capacity without incurring the high costs of real estate.

The same elevated platform could be cost-effectively used for both motor vehicles and trains. Elevated platforms made of seam-welded air hardenable stainless steel tubing would be superior to their reinforced concrete counterparts in terms of earthquake safety, maintenance requirements, building speed and appearance.

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Buildings

Many benefits can be realized from the use of seam-welded air hardenable stainless steel tubing as a structural medium in static structures, including private homes and public and industrial buildings.

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A modular building construction system consisting of prefabricated truss-assemblies bolted or otherwise joined on site is envisioned. This system can be used in conjunction with conventional materials such as wood, drywall, various compositions of siding and paneling, etc., which would be most effectively employed as "fill-in" and covering materials and not relied upon for basic building strength.

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The inherent qualities of seam-welded air hardenable stainless steel tubing enable a much higher overall cost efficiency in building construction. The basic load-bearing structure, consisting of columns and trusses of seam-welded air hardenable steel tubing, would be lightweight and inexpensive to transport, and therefore could be factory-produced off-site. Factory production via automated machinery is less expensive and results in a more standardized product than that producible by on-site skilled labor. Fast, easy, accurately aligned, on-site assembly is possible due to the inherent straightness and lack of distortion in the tube-based trusses, their lightness, and their suitability for use with standardized fittings. The tubing's high strength-to-weight ratio and stiffness-to-weight ratio enable longer spans with fewer vertical supports than can be made with conventional steel or wood.

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In addition to increased cost effectiveness, the use of seam-welded air hardenable stainless steel tubing as a structural medium in buildings yields increased resistance to collapse in fire, a reduction of the fuel available for a fire, superior performance in earthquakes, severe storms and strong winds, increased durability and energy efficiency, and less susceptibility to flood and termite

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damage. Reduction of the risk of damage by fire or natural disaster will drive insurance costs down—an important consideration for private homes as well as for hospitals, schools, hotels, factories, shopping centers and malls, industrial buildings, aircraft hangars, and other public buildings. Also, as a new structural 5 material that can compete in performance and price with wood, use of seam-welded air hardenable stainless steel tubing in building construction will reduce the rate by which we deplete our forests.

Seam-welded air hardenable stainless steel tubing offers new possibilities in architectural design. For example, it is desirable to design the interiors of many 10 large public buildings, such as airport terminals, malls, train stations, and convention halls, as large, open spaces free from support columns. With the use of the present tubing material, long spans can be accommodated without resorting to very deep trusses. Furthermore, the total dead weight of a given truss is drastically reduced, with the attendant advantage of requiring less massive support columns, 15 foundations, etc. In residential construction, roof trusses made by this system enable attic spaces free of the obstructing vertical members that are part of wood trusses.

The present invention also enables the construction of cost-effective movable and modular buildings, such as sheds, temporary buildings and mobile 20 homes.

Fluid and gas transfer piping

The present tubing system can yield substantial economic gains in the area of fluid and gas transfer, including the transfer of water, sewage and energy industry products such as crude oil, refined oil products and natural gas. Often, the 25 strength-to-weight ratio and stiffness-to-weight ratio of the pipe are important, for example where a long horizontal run is elevated from the ground or where there is internal pressure. In these cases, the high strength-to-weight ratio and stiffness-to-weight ratio of seam-welded air hardenable stainless steel tubing enable longer horizontal spans between supports and thinner walls, resulting in advantages in 30 terms of transport and placement of the pipe. Furthermore, it is envisioned that the present pipe can be produced *in situ*, in very long, continuous lengths, by the use of a mobile tube mill mounted on a truck trailer or ship, for example. Pipe thus produced in one continuous length results in far fewer joints for a given

application, which reduces the cost and maximizes the strength-to-weight ratio of the pipe.

The petroleum industry makes heavy use of tubular materials for use in lifting, transporting, and refining oil and gas. The advantages of seam-welded air hardenable stainless steel tubing mentioned above apply in this area as well. In addition, the present tubing system can be used to produce high performance, low cost lifting rods for use in reciprocating artificial lift systems. As such, a "sucker rod" made of conventional material will be replaced by a sucker rod fabricated from a tube of the present invention, with the further advantage that the interior of the tube can be used for injecting well conditioning fluids or chemicals or alternately used as additional space for flowing well product to the surface. In this application as well, the tubing may be produced in one continuous length *in situ*, with the same advantages as mentioned above.

Aircraft

The lightness, low cost and high strength and stiffness of seam-welded air hardenable stainless steel tubing make it an ideal material for aircraft structures. Seam-welded air hardenable stainless steel tubing or truss structures made therefrom could be used for many parts of an aircraft structure, from the major framing, including wing spars, to interior accessories such as seat frames. As typical aircraft materials tend to be expensive, the present invention can reduce the cost of aircraft construction with no performance penalty.

Engine components

Seam-welded air hardenable stainless steel tubing could be advantageously used for fabricating fan blades for turbo-fan engines and connecting rods for piston engines.

Ships

Framing members of seam-welded air hardenable stainless steel tubing can be used in the construction of ships, resulting in a dramatic weight savings and increased corrosion resistance in comparison with the use of traditional steel.

Heat exchangers

As the present tube is very high strength, it is useful for heat exchangers because the tube walls can be made thinner, thus improving heat transfer per unit area of tubing wall. For increased corrosion resistance, one or both sides of the tubes in a heat exchanger can be faced with a thin layer of special material to give the desired characteristics.

Bicycles

Frame weight is very important in bicycles and exotic lightweight materials like carbon and titanium have found considerable use in this application despite their very high cost. The present invention allows for the production of 5 bicycle frames, at a reasonable cost, of essentially the same weight, strength and stiffness as ones made of expensive, exotic materials. For example, drawn titanium has a greater strength-to-weight ratio on straight lengths of material. But it requires substantial wall thickness near weld zones as the metal loses strength in the heat-affected zone. The total mass of metal needed to create a bicycle of a 10 certain strength would be similar in the case of titanium and the 410 tubing of the present invention. The cost difference is estimated to be 40 fold cheaper for a frame made from the present invention.

Hollow springs

Air hardenable stainless steel inherently has very good spring 15 characteristics. The tubing disclosed herein can thus be used as a spring medium in configurations such as helical tube and torque tube. As compared to typical springs, springs of seam-welded air hardenable stainless steel tubing would be lighter due to the elimination of the unstressed central core area of the spring medium, and would have a higher resistance to corrosion. Hollow springs of 20 seam-welded air hardenable stainless steel tubing would be particularly suitable to the application of moving vehicles, where the reduction of overall vehicle weight is critical.

Personal mobility aids

The present invention makes possible the production of inexpensive, 25 lightweight and high performance devices for the aid of physically-challenged individuals, including wheelchair frames, crutches and the like.

Missile casings and rocket casings

The present tube can be advantageously employed for missile and rocket construction, as the missile and rocket walls can be made thinner and less costly 30 than with traditional materials of the same strength. Reduced wall thickness lowers drag for a given internal space.

Space and extra-terrestrial structures

The present tube can be advantageously employed in the construction of large-scale space or extra-terrestrial structures such as space stations, etc., due to 35 its low cost and high performance.

Other applications for seam-welded air hardening stainless steel tubing include the following:

cranes and gantries; fixtures for use in manufacturing, including aircraft manufacturing; supports and framing for concrete forms; catwalks and access

- 5 ways; ladders; fence posts and railings; boat masts and boat railings; hydraulic and pneumatic cylinders; tools and implements; signposts, including overhanging freeway signposts; light poles, signal light poles, and flag poles; tent poles, awning frames, umbrellas, and canopy frames; oar and paddle shafts; racquet frames, ski poles and mountain-climbing equipment; elevator cars and shafts;
- 10 highway guard rails; anti cave-in devices for construction trenches, mines, etc.; framing for dams; bleachers and temporary seating; platforms and stages; scaffolding frames and frames for temporary enclosures, such as those used for sand-blasting buildings and ships; car-top racks; optical and radio telescopes; saw horses and portable work benches; tripods, including camera tripods; vertical
- 15 towers, including telephone poles, radio transmission towers, power transmission towers, and ski lift and tramway towers; electrical and fiber optic cabling conduit; chimneys and smokestacks; furniture; and storage and pressure tanks.

Each of these applications would benefit from this inexpensive, light, strong, and corrosion-resistant tubing system. Indeed, the tubing disclosed herein

- 20 is an excellent option for any application requiring a light, strong, and/or corrosion-resistant structure.

Example 1: Tubing

A 100-foot run of tubing of 1.125" OD diameter with 0.020" wall thickness was manufactured. It was manufactured on a mill of the present invention from 3.555" width 410 stainless steel strip from Ulbrich Steel of Fresno, California, in a manner provided hereinabove.

The welding machine used on the mill was a Lincoln® Squarewave TIG 255, manufactured by the Lincoln Electric Company, of Cleveland, Ohio, and was set at approximately 35 amps in an argon atmosphere. No filler was added. The

- 30 feed speed of the stainless steel strip into the weld box was two inches per second. The welded tubing was subjected to positively controlled cooling through use of an acetylene torch positioned downstream of the weld box. The flame thereof was adjusted so the heat-affected zone cooled slowly from the upper to the lower critical temperature, the difference between the natural and the controlled cooling

rate being represented by Figure 4. We estimate that the controlled cooling rate was approximately six times the natural cooling rate. The upper and lower critical for 410 stainless is 1850° and 1450° respectively.

Example 2: Bicycle frame

5 Tubing sections from the above run were cut and assembled into a bicycle frame with other drawn tubing. The drawn tubing included in the assembled frame included 410 stainless steel drawn tubing sections of 0.5 " and 0.625" OD with 0.020" wall thickness for the rear triangle. The seam-welded and drawn tubing sections were assembled by hand via butt welding using a Lincoln® Squarewave
10 TIG 255, manufactured by the Lincoln Electric Company, of Cleveland, Ohio using standard 410 stainless filler rod supplied by San Diego Welding Supply of San Diego, California and modulating the amperage of the welder between approximately 8 to 10 amps. The assembled frame was then heat treated in a batch-type vacuum furnace to a range of 1900 to 2000° F. Certified Metalcraft of
15 El Cajon, CA provided the heat-treating furnace.

This bicycle using this frame was subjected to rigorous field-testing in remote and difficult terrain and was found to be light, responsive and suitably stiff. The frame did not fail. No performance differences between the drawn and seam-welded portions of the frame were noticed.

20 **Example 3: Tension Fatigue at Room Temperature**

Fatigue testing at room temperature was performed to generate data concerning the strength of a hardened, seam-welded stainless steel tube of the present invention that was hardened in a manner similar to that of the bicycle frame.

25 We believed the testing would show none of the cracks typically found in the heat-affected zone of finished tubing of the prior art.

The tube tested, after it was hardened, was a piece of the tube run described in Example 1. The test piece was tested in accordance with MIL-STD-1312-11A. The work piece was subjected to 130,000 cycles with a low load of
30 500 pounds (7,000 psi) and a high load of 5,000 pounds (70,000 psi) of axial tension. This piece was not tested to failure.

This testing proved that at least one method of the present invention does not produce the tubes of the prior art that had visible and invisible cracks.

Example 4: Axial Tensile Test

The sample was tested in accordance with ASTM F 606-00 to determine the tensile strength of a tube of the present invention. The work piece resulted in 14,453 lbs applied (206,000 psi). Book value of hardened 410 is 200,000 to 5 210,000 psi. These data prove that the weld zone does not provide any weakness in the overall structure such that this material is equivalent to a drawn tube of similar diameter, wall thickness and material.

Example 5: Tube Mill

Figures 2 and 3 provide side and top views of a tube mill of the present 10 invention. Strip 10 is fed through sizing and shaping rollers 16 that is then fed into a welding box 20. Downstream of the welding box 20 is a torch assembly 18 used to control the cooling rate of the welded piece. The welded piece is then sized in sizing rollers 14 to produce the seam-welded air hardenable tubing 12 of the present invention.